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SOME HIGH-TEMPERATURE EFFECTS IN APPLES: CONTRASTS IN THE TWO SIDES OF AN APPLE

BY

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SOME HIGH-TEMPERATURE EFFECTS IN APPLES: CONTRASTS IN THE TWO SIDES OF AN APPLE[1]

By CHARLES BROOKS, *Senior Pathologist*, and D. F. FISHER, *Pathologist, Fruit Disease Investigations, Bureau of Plant Industry, United States Department of Agriculture*

INTRODUCTION

It is well known that apples, like other plants, have very definite temperature responses and limitations. Their limit of resistance to low temperatures has received a great deal of attention, and in many cases has been fairly well established. Their limit of resistance to high temperatures, and their response to extreme heat, has received much less consideration. The present paper does not pretend to record any definite heat limit for apples, but is a report of the effect of certain high-temperature periods upon the apple fruit. The unprecedented heat wave of 1918 and the exceedingly hot weather of 1924 have furnished the conditions of the studies reported here.

THE EASTERN HEAT WAVE OF 1918

The July of 1918 was the coolest July on record for Virginia, and the coolest July since 1891 for Maryland and Delaware. The July departure from normal in Virginia was −3.7° F. and in Maryland and Delaware −2.7°.

The rainfall for July was also below normal in most sections of the above States. The average for Virginia was 3.50 inches, or 0.81 inch below normal, and the average for Maryland and Delaware was 3.05 inches, or 1.17 inches below normal. The rainfall for Washington, D. C. for the month was 3.79 inches, and the rainfall for Winchester, Va., was 2.20 inches. Washington had moderate rains during the last week of July, but Winchester and the Shenandoah Valley had little rain during this period. The rainfall, in general, was well distributed throughout the month. The prevailing winds were light, and this, together with the low temperatures, prevented excessive evaporation from the plants and soil. Plants, in general, showed little if any indication of drought, and apples made a good growth, with apparently no checking effect from the relatively low rainfall.

The weather during the first four days of August was cool to seasonable, but on August 5 the temperature began to climb, and the heat wave continued for more than a week. On August 6 the maximum temperature at Winchester, Va., was 106°, at Martinsburg, W. Va., 106°, at Baltimore, Md., 105°, and at Washington, D. C., 107°. On August 7 the maximum temperature at Winchester was 103°, at Martinsburg 104°, at Baltimore 105°, and at Washington 105°. The maximum and minimum temperatures for Washington, D. C., both preceding and during the heat wave, are shown in the

[1] Received for publication Feb. 10, 1925; issued January, 1923.

curves of Figure 1. The records from the other United States Weather Bureau stations of the section give very similar temperature curves for this period. For duration and intensity, the heat wave that prevailed from August 4 to 14 was ranked by the United States Weather Bureau as the most extreme on record for the section. The effect of the heat wave upon the people was severe. In Virginia 288 prostrations and 21 deaths were reported; in Baltimore 116 prostrations and 16 deaths.

The high temperatures were accompanied by a relatively high percentage of sunshine, especially during the first part of the period.

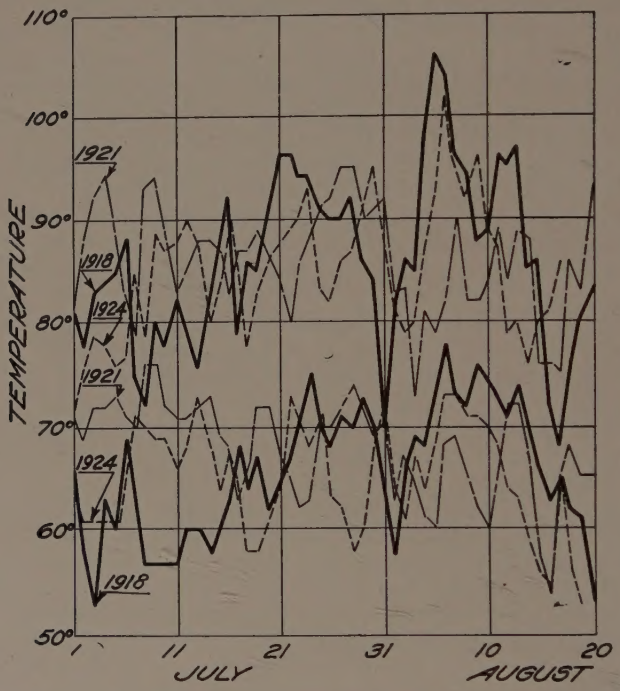


FIG. 1.—Maximum and minimum temperatures for Washington, D. C., during July and the first 20 days of August in 1918, 1921, and 1924. After United States Weather Bureau Climatological Data (*12*)

At Washington, D. C., the percentage of possible sunshine on August 5 was 81, on August 6, 100; on August 7, 77; and on August 8, 74.

A thunderstorm occurred on August 7, with a precipitation of 1.08 inches at Winchester, 0.32 inch at Martinsburg, 0.29 inch at Baltimore, and 1.30 inches at Washington. There were local showers on August 9, and a more general rain on August 10 and 11.

LEGEND FOR PLATE 1

A.—York Imperial from Gerrardstown, W. Va., as affected by the heat wave of 1918. Illustration shows condition of the fruit on August 30, about three weeks after the period of greatest heat

B.—Cross section of the apple shown in A

C.—Ben Davis from Vienna, Va., as affected by the heat wave of 1918. The painting shows the condition of the fruit on August 31

D.—Cross section of the apple shown in C

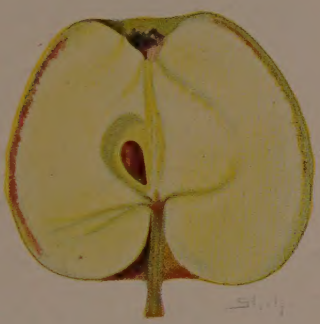
E.—A common form of heat injury on York Imperial. The circular depression was at the margin of the region of greatest exposure

F.—Cross section of the apple shown in E

A

B

C



D

E

F

EFFECT OF THE HEAT WAVE OF 1918 ON APPLES

The losses in tomatoes, apples, and other crops was the subject of much comment at the time of the heat wave, but apparently was not made a matter of published record. The injuries to the fruit of the apples ranged from isolated spots of brown, spongy tissue in different parts of the flesh through various stages of partial collapse to a completely baked appearance that sometimes involved the entire apple.

Northwestern Greening apples were the most severely affected. In sections of the Shenandoah Valley near Inwood, W. Va., the crop was practically destroyed, scarcely any sound apples being left on the trees. Sometimes the injury was confined largely to the exposed side of the apple, but it was quite common for the entire apple to be involved and to have the appearance of having been actually cooked to the core. In some cases the injury was largely on the apples that had at least a moderate degree of exposure to sunlight, but in others the greener apples from the most shaded locations were completely "baked," taking on a brown, mushy, watery appearance and soon dropping from the tree.

Roberts (*7*)[2] reported an injury of Northwestern Greening in Wisconsin that was first noticed about August 20, 1918. He attributed the trouble to the extreme drought that prevailed. The apples did not become "baked" as described above, but developed various forms of "crinkle" and "cork."

Other varieties of apples in the Shenandoah Valley showed various degrees of injury from the heat wave, but none of them the complete collapse that was found with the Northwestern Greening. The York Imperial developed a large percentage of apples with more or less brown, spongy tissue. In the more extreme cases practically all of the outer flesh of the apple was killed, soon becoming brown and collapsed. The skin usually retained its normal appearance, but in some instances a part of the skin was also killed, resulting a little later in wrinkled and corrugated apples with strips or islands of sound green tissue partially or entirely surrounded by brown dead areas. (See pl. 1, A and B.) Much of this fruit dropped from the tree, yet an almost infinite variety of malformed apples was left to be sorted out at picking time.

A common form of injury on the York Imperial and a number of other varieties was that of spots of spongy or corky tissue in the flesh of the apple. The spots varied from one-fourth to three-fourths of an inch in diameter. Sometimes a spot stood alone, but more often there were a number of spots, or a more or less continuous band of brown, corky tissue. The spots were usually within a half inch of the surface of the apple and the skin above apparently sound and normal, but later becoming more highly colored than the surrounding area. At picking time the location of the spots was sometimes indicated by a slight depression as well as by heightened color. The injury usually occurred on the exposed side of the apple and frequently at the margin rather than the center of the most exposed area.

The most common form of injury on the Ben Davis variety was a browning of the tissue around the core with the outer flesh entirely

[2] Reference is made by number (italic) to "Literature cited," p. 15

normal, but in an orchard at Vienna, Va., the tissue immediately beneath the skin of the apples was brown and collapsed, making an almost complete layer of dead tissue surrounding the sound interior portion of the apple. The condition of these apples on August 29 is shown in C and D of Plate 1. The apples had continued to enlarge, but the surface of the apple had taken on a peculiar bumpy or warty appearance, the elevations and depressions apparently being due to variations in the thickness of the sound surface layer and the extent of the collapse in the tissue beneath.

A Ben Davis tree affected with root rot was found in this Vienna orchard. As a result of the weakened condition of the tree, the foliage was scant and the small and medium-sized apples were freely exposed to the intense sunlight, but the heat wave left no evidence of injury on the fruit. The contrasts in the condition of the apples on the diseased and healthy Ben Davis trees made it strikingly evident that growth conditions played a very important part in determining the effect of the heat wave.

THE HOT WEATHER OF 1924

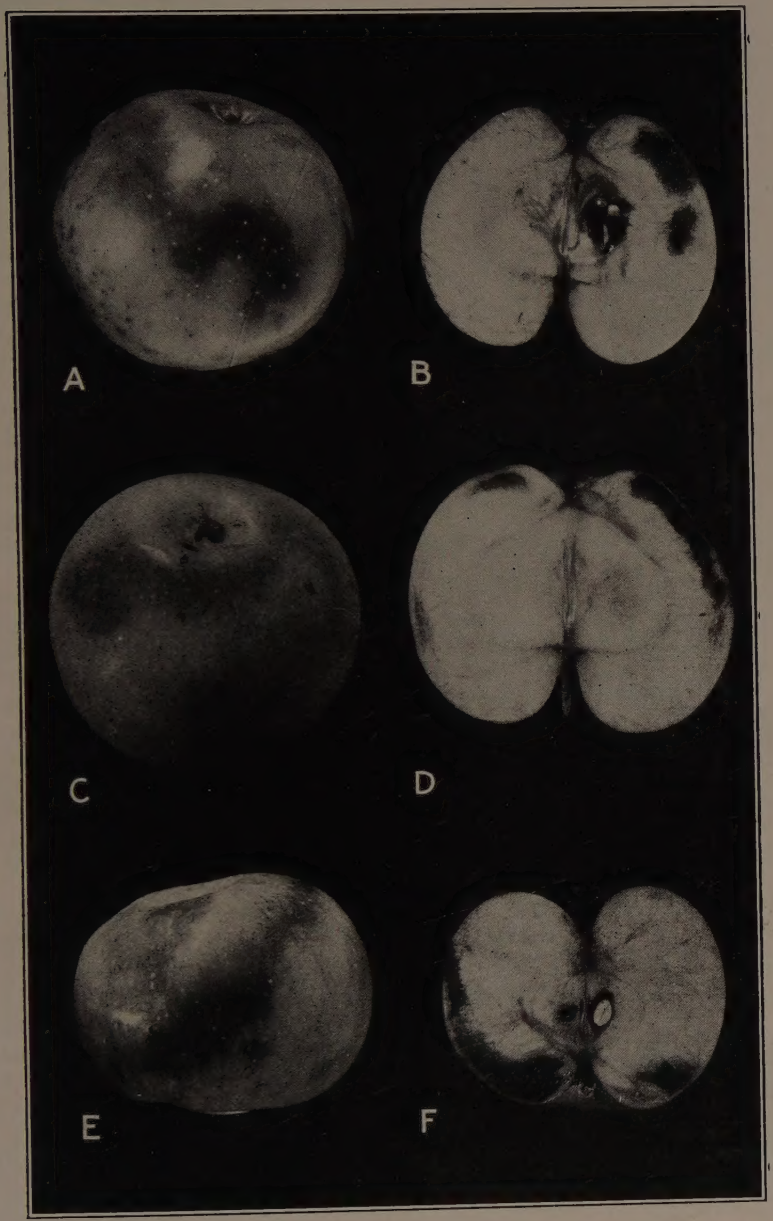
Since 1918 the section under consideration above has had no July so cool and no August so hot as reported for that year. In Maryland and Delaware the departure from normal in July in 1918 was −2.7° F. and the departure in August from normal +2.6°, with 109° as the highest temperature recorded in August. In 1920 the July departure from normal was −2.2° but the August departure from normal was only +0.2°, and the highest temperature for August 95°. In 1921 the departure from normal in July was +2.50°, and the departure from normal in August was −2.1°, with 98° as the highest temperature for August. The maximum and minimum temperatures for Washington, D. C., in July and August, 1921, are shown in Figure 1.

In 1924 the weather conditions for the section were somewhat similar to those of 1918, but much less severe. In Maryland and Delaware the July departure from normal was −2.2° F. The August departure from normal was 0.0°, but there was a period of extreme heat from August 5 to 9 in which a maximum of 103° was reached on August 6. This was the highest temperature for these States since 1918, and the first August temperature since 1918 that reached 100°. The extreme heat was in decided contrast to the relatively cool weather that had preceded. (See fig. 1, record for Washington, D. C.) The July rainfall for Maryland and Delaware was 2.48 inches, or 1.86 inches below normal, and for Virginia was 3.61 inches, or 0.98 inch below normal.

EFFECT OF THE HOT WEATHER OF 1924 ON APPLES

As pointed out above, the July temperatures for 1924 were not so low nor the early August temperatures so high as those of 1918. The injury to apples was correspondingly less; in fact, so little occurred that it received no general attention. Such troubles as were observed by the writers were confined almost entirely to Northwestern Greening and York Imperial varieties.

On Northwestern Greening, the injury was evident to surface view as slightly depressed areas having a darker and somewhat



A.—Northwestern Greening from Arlington, Va., August 28, 1924. The dark band had a watery appearance, but retained its green color

B.—Longitudinal section of apple shown in A. The brown water-soaked tissue was beneath the dark band

C.—Northwestern Greening from Snow Hill, Md., September 3, 1924. The skin of the injured area retained its green color

D.—Longitudinal section of the apple shown in C. The affected tissue came very near to the surface of the apple

E.—York Imperial from Snow Hill, Md., September 3, 1924. The slightly sunken and more highly colored band was at the margin of the blush area

F.—Longitudinal section of the apple shown in E. The affected tissue was brown and spongy and was located beneath the sunken area

water-soaked appearance. Upon cutting into the apple, the tissue beneath was found to be brown and watersoaked and sometimes bordered by fairly typical water-core. (See pl. 2, A, B, C, and D. The affected tissue did not dry out rapidly or become greatly collapsed. The greatest injury observed was in an orchard at Snow Hill, Eastern Shore of Maryland, where possibly 5 per cent of the crop was affected with the above trouble.

The first report of injury to York Imperial came from Snow Hill, Md., on August 14, 1924. Specimens forwarded to the Department of Agriculture at that time showed slightly depressed areas on what was evidently the exposed side of the apple. The tissue beneath was brown, moist, only slightly collapsed, and often bordered with water-core.

The Snow Hill section was visited on September 3, and it was found that while the injury was of general occurrence throughout the orchards it reached serious proportions only in certain localities where the soil was poorly drained. This soil had been somewhat waterlogged early in the season but had become quite dry at the time of the heat wave, apparently resulting in a sudden shortage of water with trees that had started the season with an excessive supply.

On September 3 the injury on the York Imperial apples appeared to surface view as spots and bands, usually located at the margin of the blush area. The affected tissue was usually slightly depressed and had indications of a dark or water-soaked tissue showing through from beneath. In cross section, it was found that in some cases the underlying tissue was dry and collapsed, sometimes to the extent of developing definite pockets, while in others a part of the affected tissue was dry, but with water-soaked or water-core tissue adjoining, and in still others the entire mass of tissue was wet and spongy. In many cases the apples that had injuries near the surface also had water-core deeper in the flesh. (See pl. 2, E and F; and pl. 3, A, B, and C.)

While it seems probable that the soil-moisture conditions in the orchards had played a part in determining the extent of the injury, the location of the affected apples on the tree and the location of the injury on the apples made it evident that the exposure to sunlight was a most important determining factor in the development of the disease. The occurrence of this particular type of injury after the heat wave of 1918 and again after the hot weather of 1924 furnished further evidence of its association with heat and sunlight.

HIGH TEMPERATURES IN THE IRRIGATED ORCHARDS OF THE NORTHWEST

The maximum temperatures shown in Figure 1 for the heat waves of 1918 and 1924 are not higher than apples frequently endure without injury in the more arid sections of the country, where almost continuous sunshine prevails. The orchards of Wenatchee, Wash., may be taken as an illustration. Figure 2 gives some of the June and July temperatures for Wenatchee as reported by the United States Weather Bureau. The maximum temperature in 1917 was 106° F.; in 1919 it was 107°, and in 1924, 110°. With the exception of 1924, however, the heat waves were preceded by relatively high

A.—Cross section of a York Imperial apple from Snow Hill, Md., September 3, 1924. A part of the affected tissue had dried out sufficiently to develop pockets in the flesh, while another part was completely water-soaked. Water-core was evident in the region of the larger vasculars

B.—Longitudinal section of a York Imperial apple from Snow Hill, Md., September 3, 1924. The affected tissue was dry and spongy, with occasional pockets developing. Water core was evident along the larger vasculars

C.—Longitudinal section of a York Imperial apple from Snow Hill, Md., September 3, 1924. The flesh on the exposed side of the apple was brown and water-soaked, but the peel was a bright red. Water-core had developed near the core

D.—Winter Banana from Rock Island, Wash., picked July 8, 1924, and photographed after becoming withered. Note the deep depression at the margin of what was the exposed area

E.—Rome Beauty from Wenatchee, Wash., picked July 19, 1924. The deep depression was at the margin of what was apparently the most exposed area

F.—As E, but more severely injured

temperatures. In 1917 there had been 15 days prior to the heat wave when the temperature had risen to 90° or above, and the average maximum temperature for the 24 days preceding the hot weather was 87.5°. In 1918 there had been 14 days prior to the heat wave when the temperature had risen to 90° or above, and the average maximum temperature for the immediately preceding 24 days was 88.0°. In 1919 there had been 14 days prior to the heat wave when the temperature had risen to 90° or above, and the average maximum for the immediately preceding 24 days was 89.8°.

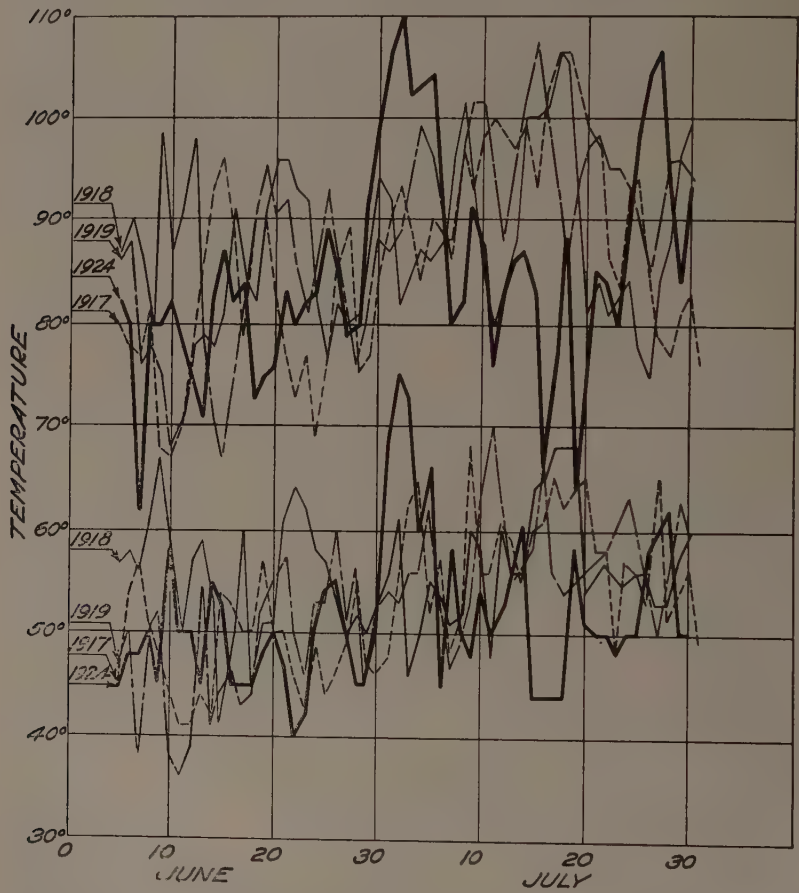


FIG. 2.—Maximum and minimum temperatures for Wenatchee, Wash., for the period June 5 to July 30 in 1917, 1918, 1919, and 1924. After U. S. Weather Bureau Climatological Data (*11*)

In 1924 the situation was quite different. Not only did the heat wave come earlier in the season and the temperatures reach a higher point than in the other years, but there had been no preceding hot weather. There had not been a single day prior to the heat wave when the temperature rose as high as 90° F., and the average of the maximum temperatures for the 24 days preceding the heat wave was only 79.6°.

A.—Spitzenburg (Esopus), Wenatchee, Wash., September 16, 1924. The depression was at the margin of what was apparently the most exposed area

B.—Longitudinal section of the apple shown in A

C.—As A, but showing a milder form of the injury

D.—Longitudinal section of the apple shown in C. The pockets and corky tissue were beneath the surface depression

E.—Rome Beauty, Wenatchee, Wash. Pulled from shade into the sunlight September 2 1924. The injury became evident a few days later. Photographed on October 2

F.—As E, but a more extreme injury

EFFECT OF HIGH TEMPERATURES ON THE NORTHWESTERN APPLES

A comparison of Figures 1 and 2 shows that the high temperatures at Wenatchee in 1917, 1918, and 1919 surpassed those of 1924 in Maryland and Virginia and equaled those of the record-breaking eastern heat wave of 1918. But aside from occasional slight sunburns, the apples of the Wenatchee Valley showed no injury from these high temperatures, indicating a higher degree of resistance to heat than that possessed by eastern apples.

In 1924, however, the Wenatchee temperatures soared above any recorded for the eastern sections in question, and this immediately following a period of unusually low temperatures. About a week to 10 days after this heat wave, injuries became evident on the apples. They were of the same type as those already reported for eastern apples following the hot weather of 1924: Slightly sunken areas with brown, collapsed, watersoaked tissue beneath and occasional evidences of water-core in adjacent tissue. The affected tissues soon collapsed, producing deep depressions on the surface or definite pockets beneath.

The injuries were practically all on the exposed side of the apple, and usually at the margin rather than at the center of the most exposed areas. (D, E, and F, pl. 3; and A, B, C, and D, pl. 4.) The disease was found under various orchard conditions, but was most common on trees growing in sandy or gravelly soil.

The Winter Banana and Rome Beauty apples were most seriously affected, but even with these varieties only a small percentage of the crop showed definite injury. In spite of the intense heat, the loss in the crop was not sufficient to receive any general consideration.

PREVIOUS EXPOSURE AS A FACTOR IN DETERMINING THE HEAT RESISTANCE OF APPLES

To draw any definite conclusion as to the cause of the difference in susceptibility to heat of apples from different sections of the country, or from different trees of the same section, would require consideration of a number of factors. The orchards of the Wenatchee Valley are under irrigation and usually well supplied with water, while the amount of soil moisture in eastern orchards is largely determined by the rainfall. Differences in cultivation, soil, subsoil, and cover crop may account for contrasts between different sections of the country and also for contrasts between different trees in the same orchard. While none of these factors should be overlooked, the data reported above seem to indicate that the temperatures to which apples have been previously subjected may play a very important part in determining the degree of their heat resistance and that ability to endure high temperatures can be greatly increased by gradual hardening to heat. All of the injuries described above have occurred when a period of hot weather had been preceded by one of unseasonably cool weather.

The Wenatchee apples, which are subjected to almost continual burning sunshine throughout the season, are able to withstand an air temperature several degrees higher than that which caused serious injury in eastern orchards. These northwestern orchards are not all sufficiently well supplied with water to make soil-moisture conditions an adequate explanation for this contrast in heat resistance,

and it is undoubtedly to be partly, if not largely, explained on the basis of a gradual development of resistance to bright sunlight and high temperatures.

An example of the lack of resistance to heat and sunlight is seen in the sunburns and blisters that develop on poorly exposed apples when they are suddenly brought into the open by the weighing down of heavily loaded limbs. In the summer of 1924 a definite test of this point was made at Wenatchee, Wash. On September 2, shaded Rome Beauty branches were pulled into bright sunlight and tied so that apples which were formerly shaded would be freely exposed. At that time the air temperature in the shade was 90° F., and the temperature of the exposed side of apples in full sunlight 112°. The maximum temperatures at Wenatchee for September 3 to 7, inclusive, as reported by the Wenatchee station of the Weather Bureau were 96, 98, 98, 95, and 91°, respectively. On September 5 the apples had begun to show blisters, and on October 2 it was found that all but 2 of the 18 apples which had been pulled into the bright sunlight showed distinct injury. One of the injured apples showed a definite "crinkle" condition (pl. 4, E), 3 a bronzing or blistering, and 12 a soft, cooked condition on the exposed side (pl. 4, F). The apples that had been continuously in an exposed position on the tree showed no injury, making it evident that the injury on the apples of the shifted limb was due to the sudden change in exposure rather than to the extreme heat.

CONTRASTS BETWEEN THE DIFFERENT PARTS OF THE SAME APPLE

The different parts of a particular apple are not usually subjected to the same temperature and apparently do not have the same resistance to high temperatures.

On September 10, 1923, a record was made of the temperatures of Winesap apples at Wenatchee. It was found that at about 3 p. m. the sunny side of exposed apples had a temperature of 104° F., and the shaded side a temperature of 91.4°, while completely shaded apples had a temperature of 82.4°. The air temperature in the shade was approximately the same as that of the shaded apples. In 1924 further temperature records were made in the orchards near Wenatchee (Table I).

TABLE I.—*Fruit and air temperatures in apple orchards at Wenatchee, Wash., 1924*

Variety and treatment	Hour	Date	Temperature			
			Exposed side of exposed apple	Shaded side of exposed apple	Apple in shade	Air in shade
			°F.	°F.	°F.	°F.
King David:						
Heavy irrigation	3.30 p. m.	July 25	116.0	109.0	98.0	100.0
Do	4.15 p. m.	July 26	115.3	106.8		98.0
Light irrigation	do	do	114.0	106.5	100.7	98.0
Normal irrigation	10 a. m.	Aug. 3	89.0	80.0	73.6	75.0
Winter Banana:						
Normal irrigation	2.45 p. m.	Aug. 9	108.7	97.0	86.4	86.0
Do	2.30 p. m.	Aug. 12	99.8	95.0	89.0	92.0
Jonathan, normal irrigation	3. p. m.	Sept. 2	108.8	97.2	88.4	80.0
Winesap:						
Normal irrigation	do	do	105.0	96.0	87.0	80.0
Do	do	Oct. 1	84.7	72.8	66.7	67.8

On August 8 and 9, during the latter part of the hot spell of 1924, similar temperature records were made in the experimental orchards at Arlington, Va. (Table II).

TABLE II.—*Fruit and air temperatures in apple orchards at Arlington, Va., 1924*

Variety	Hour	Date	Temperature			
			Exposed side of exposed apple	Shaded side of exposed apple	Apple in shade	Air in shade
			°F.	°F.	°F.	°F.
Grimes	2.15 p. m.	Aug. 8	105.3	94.8	90.5	89.6
Summer Rambo	2.30 p. m.	do	108.3	93.4	87.1	88.9
Ben Davis	2.45 p. m.	do	105.1	93.2	----------	89.1
Bietigheimer	3 p. m.	do	111.7	95.7	87.8	88.2
Nickajack	1 p. m.	Aug. 9	111.4	104.4	95.7	92.3
Smith Cider	1.15 p. m.	do	100.4	97.9	92.1	88.2

Tables I and II show that the blush side of an apple may be 10 to 16° F. warmer than the shaded side, and 12 to 25° warmer than the air in the shade.

All of the apple temperatures were taken by pushing the bulb of a thermometer tangentially beneath the skin and allowing it to remain in that position till the temperature became constant. This gave the temperature at a depth of one-eighth to three-sixteenths inch in the flesh rather than immediately beneath the skin.

Harvey (*2*), working with thermal couples and making tests earlier in the season, reported still greater contrasts in the temperatures on the two sides of the apple. Records taken in Wisconsin July 13, 1922, between 3 and 4 p. m., showed that with the air temperature at 70° F. and the temperature of the shaded side of a red apple at 81°, the temperature of the exposed side might be as high as 103°, making a difference of 22° between the two sides of the apple.

Overholser, Winkler, and Jacob (*6*) found that under California conditions the temperature of exposed apples averaged about 14° F. higher than the temperature of apples from the shady side of the tree.

Stevens and Wilcox (*10*) reported that on clear days the temperature of berries exposed to the sun was considerably above that of the surrounding air, and that currants from Milton, N. Y., in bright sunlight had a temperature 11° F. higher than similar fruit in the shade.

It will be seen from these various records that exposed fruit actually endures very high temperatures, even under moderate weather conditions, and that the two sides of an apple are accustomed to very different degrees of heat. The two sides of an apple are also naturally accustomed to different degrees of light, but the writers are of the opinion that high temperature rather than intense sunlight is the determining factor in cases of injury.

If we can assume that the more exposed side of an apple develops a greater endurance of heat than the more shaded part, just as the exposed apples have a greater endurance than the shaded ones, we have a basis for a possible explanation of some of the peculiar patterns produced in cases of heat injury. It was pointed out in connection with a number of the injuries previously described that the affected

tissue was located at the margin rather than at the center of the most exposed area (pl. 1, E, F; pl. 2, E; pl. 3, D, E, F). The cause of this difference in susceptibility of the different parts of the same apple has been a matter of considerable speculation. The only explanation that seems possible at present is that the various parts of the apple gradually become hardened to different degrees of heat and sunlight, depending upon their relative position, and therefore show different degrees of susceptibility to heat injury when critical temperatures occur. In addition it should be borne in mind that the position of the fruit and foliage is not a fixed one. Changes in the position and exposure of the apples, due to shifting winds and the increasing weight of the crop, make it possible for new and less-resistant apple surfaces to be brought temporarily or permanently into the region of most intense sunlight and heat. This shifting of the center of exposure and the differences in the degree of hardening to heat seem to offer an explanation for the injuries that are often found at the margin of what has evidently been the region of greatest exposure.

The nature of this hardening to heat has not been made a subject of special study. The more exposed apple surfaces often have more yellow and red pigment than the marginal ones, but it is not believed this higher coloring has any great significance as a protection against heat. Harvey (*2*) makes the statement that "green parts of fruits are heated to a greater degree than red parts," and that "the development of red on the exposed side of the apple tends to prevent excessive heating of the surface." He gives no data to support this statement, however, and the writers are not aware of any physical or physiological basis for concluding that the red color in itself serves as a protection from heat. On the contrary, Stahl (*9*) and Smith (*8*) have shown that in direct sunlight red leaf tissue actually becomes warmer than similar green tissue.

Zschokke (*13*) reported that the thickness of the cuticle of the apple skin varied with the exposure of the fruit to the sun, and Magness and Diehl (*5*) found that the subepidermal region of the blushed side of an apple might be distinctly thicker and have more cell layers than the corresponding tissue on the unblushed side. It is possible that this thickening of the skin of the apple on the exposed surfaces may serve as a protection against heat injury.

In the summer of 1924, studies were made in which the sap concentration of the exposed side of apples was compared with the sap concentration of the shaded side of the same apples. In preparing the samples of tissue for these tests, the apples were quartered in the direction of the core, and the quarters from the exposed side placed in one lot and the quarters from the opposite side in another. Eight or ten apples were usually combined to make one set of samples (see Table III). The tissue was ground in a small meat-chopper and the juice extracted by means of a tincture press, care being taken to give equal pressure to the different samples. The osmotic determinations were made within a few hours of the time of extraction, usually within one hour. The results are shown in Table III. The apples described as slightly sunburned were so freely exposed to sunlight that they had developed a slight bronze; those described as having a normal blush were freely exposed; while those with a slight blush were from shaded limbs in the interior of the tree.

TABLE III.—*Osmotic pressure of juice from the exposed side of Winter Banana apples as compared with that from the shaded side of the same apples, Wenatchee, Wash., 1924*

Date and time of collecting	Condition of tree	Condition of apples	Number of apples used in samples	Osmotic pressure in atmospheres	
				Exposed side	Shaded side
July 22, 10.30 a. m.	Somewhat weak	Normal blush	10	16.98	16.36
Do.	do.	Slightly sunburned	10	19.61	18.77
Do.	Normal	Normal blush	8	15.04	13.95
Do.	do.	Slightly sunburned	8	15.88	13.95
Aug. 5, 10 a. m.	Vigorous	Slight blush	10	15.64	15.16
Do.	do.	Normal blush	10	16.31	16.00
Do.	do.	Slightly sunburned	10	19.13	17.08
Do.	Normal	Slight blush	10	16.24	15.64
Do.	do.	Normal blush	13	17.08	16.24
Do.	do.	Sunburned	8	19.85	17.08
Aug. 14	Lacking in vigor	Normal blush	4	15.52	15.40
Do.	Vigorous	do.	4	17.20	15.28
Aug. 18, 11 a. m.	Normal	do.	10	14.56	14.08
Aug. 21	do.	do.	10	17.08	16.12
Do.	Vigorous	do.	10	16.35	14.80

It will be seen from the data of Table III that the sap from the exposed side of the apples had a higher concentration than that from the shaded side. With the apples that had grown in the shade and had but a slight blush the contrast was small. With the well-exposed apples that had a normal blush, the sap concentration on the exposed side as measured in osmotic pressure was about three-fourths of an atmosphere higher than that on the shaded side. With the slightly sunburned apples the osmotic pressure of the juice from the exposed side was almost two atmospheres higher than the osmotic pressure of the juice from the shaded side.

The above results do not show the contrast in sap concentration between the most exposed area of the apple and that immediately adjoining it, but the fact that the exposed side of exposed apples has so much greater sap concentration than the opposite side of the same apples would suggest that differences in sap concentration might be a factor in bringing about the contrasts in heat resistance found in adjacent tissues subjected to different degrees of exposure.

HEAT INJURY AS RELATED TO DROUGHT INJURY

In pointing out certain injuries as typically heat effects, the writers are aware that similar, or possibly in some cases identical, troubles have been credited to other causes.

McAlpine's (*3*, *4*) photographs and descriptions would indicate that many of the apples which he has included under the term "crinkle" or "confluent bitter pit" are of the same type as those under consideration in the present paper. He considers these troubles as a form of bitter pit, due to a bursting of cells resulting from excessive water pressure.

Roberts (*7*), as already pointed out (p. 3), was of the opinion that the injury on Northwestern Greening in Wisconsin in 1918 was probably due to the extreme drought that prevailed during that season.

Brooks and Fisher (*1*) considered injuries of the type under discussion as forms of "cork," known locally as "hollow-apple" and "York spot." They considered "cork" a form of drought injury, but pointed out that the occurrence of "York spot" and "hollow-apple" was influenced by exposure to sunlight, as well as by soil moisture and other soil conditions.

The data reported in the present paper indicate that heat injury of apples is greatly influenced by soil-moisture conditions. The heaviest losses in the orchards at Snow Hill, Md., were in sections where the trees were likely to suffer from a sudden shortage of soil moisture. The eastern heat waves of 1918 and 1924 were both preceded by periods of relatively low rainfall. The high resistance of western apples to heat is undoubtedly due, in part, to the relatively abundant soil moisture of the orchards and the probable accompaniment of heavy transpiration.

Heat injury and drought injury of apples appear to be closely related and to gradually shade into one another. It is entirely possible that heat injuries of the type described in this paper are, in last analysis, a form of drought injury, due to a rapid desiccation resulting from the heat rather than to the tissue reaching any actual heat limit. This hypothesis, however, does not eliminate heat as the significant initiating factor in the injuries under consideration.

SUMMARY

The injuries to apple fruit resulting from certain periods of high temperature have been described and attention called to the fact that the effect of a particular temperature has varied with the conditions under which the fruit was growing.

The losses from heat have occurred when extremely high temperatures have been preceded by periods of relatively cool weather.

A shortage of soil moisture has apparently been a factor in the development of heat injury in many of the cases reported.

Starved or stunted apples have shown a greater resistance to heat injury than those that were making a normal or rapid growth.

The location and the pattern of heat injuries have apparently often been determined by the extent of the previous exposure, fruit surfaces that have been previously exposed to strong sunlight being more resistant than those that have been partially protected.

The exposed sides of exposed apples may have temperatures 10 to 16° F. higher than the shaded sides of the same apples and 12 to 25° higher than the air in the shade.

The exposed sides of exposed apples have a uniformly higher sap concentration than the shaded sides of the same apples.

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